NOX

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APPLIED RESEARCH DEPARTMENT

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RADAR SET AN/APQ-89; DRIFT ANGLE GROUND SPEED ATTACHMENT (U)

QUARTERLY PROGRESS REPORT FOR PERIOD ENDING

30 SEPTEMBER 1961

WEPTASK RAV32F030, Amend. 1, Problem 2b

This project is a continuation of work previously reported under the heading:

DRIFT ANGLE AND GROUND SPEED MEASURING EQUIPMENT, WEPTASK RAV32F024

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PREFACE

The work on drift angle and ground speed attachments for Radar Set AN/APQ-89 was authorized by WEPTASK RAV32F030, Amend. 1, Problem 2b. It is a continuation of the work performed last year under WEPTASK RAV32F024. Primary objectives of the project are to modify the design of the Drift Angle Attachment for use at K_a-band, and to develop a technique for measuring ground speed using methods similar to those used in the Drift Angle Attachment. Both attachments are to be flight tested as a part of this program.

Previous work on this project is described in U.S. Naval Avionics Facility, Indianapolis, Confidential technical reports TR-5, TR-22, and TR-56.

Prepared by:

Robert N. McCaffrey
ROBERT N. McCAFFREY

Approved by:

Charles W. May
C. W. MAY
Acting Chief of Radar Microwave Branch, 832

F. A. Marasco
F. A. MARASCO
Manager of Experimental Research Division, 830

J. F. Peoples
J. F. PEOPLES
Acting Director of Applied Research Department, 800

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I. INTRODUCTION

The U.S. Naval Avionics Facility, Indianapolis, has designed and flight tested a drift angle attachment for an attack radar system, utilizing the intermodulation Doppler spectrum obtained from the non-coherent radar. The results of the flight tests indicated that the attachment would be a valuable addition to X-band radar sets capable of supporting it, and that further work should be expended in increasing its range of usefulness.

This project is the next step in the development of a small lightweight attachment to modern attack radar systems which will provide essential navigation information. Conventional Doppler navigators are too large, too heavy, and too expensive for many applications. By utilizing radar equipment already present in an aircraft, the proposed attachment can be made small, light, inexpensive, and easy to maintain.

This project has two main objectives. One is to modify the design of the present Drift Angle Attachment as necessary for use at K_a-band, and to adapt it for use with Radar Set AN/APQ-89(XAN-1). The other objective is to develop a technique for extracting ground speed information from the radar signal. This is to be done in a manner which is compatible with the Drift Angle Attachment, and compatible with the requirements of small size and simplicity of design.

II. WORK FOR LAST TWO QUARTERS

The work during the quarter previous to this one was of such a nature that a detailed TR type of report was not justified. Therefore, a letter report was used. Since the letter did not receive wide distribution, the present report will be a summary of the work accomplished during the past six months.

A. GROUND SPEED ATTACHMENT

Work on the ground speed attachment for the past six months has been concentrated on the design and breadboarding of circuits to instrument the RMS-comparison technique of the variable-noise method described in reference 1. A detailed description of this work is given in Appendix A of this report.

A crossover frequency tracker has been designed and breadboarded. This, the heart of the computer, is composed of a balanced modulator, fixed band-pass filter, detector, and electronically tuned oscillator. A second mixer finds the difference frequency between the oscillator and the fixed filter output. The output is a single frequency which indicates the portion of the Doppler spectrum being sampled.

The balanced modulator is built around a type 7360 beam-switching tube for a high degree of carrier suppression, which will permit the use of the very low-frequency portion of the Doppler spectrum.

The fixed filter is an electro-mechanical rod-type filter, which provides a narrow bandwidth and high Q at the frequency of interest. Three different bandwidths have been pu.chased so that the effect of bandwidth upon operating characteristics can be observed.

The scheme of mixing the oscillator signal with the filter output to determine the frequency being sampled permits the fixed filter to drift without affecting system accuracy, and eliminates the necessity for an extremely accurate measurement of the oscillator frequency.

A cross-axis counter for measuring the output frequency has been designed, and the essential portions of it have been breadboarded. A servo system will be added later to average the radom fluctuations and to make the frequency information available to external equipment.

The crossover frequency tracker and the cross-axis counter breadboards were combined, and the Doppler signals from previously-obtained flight-test tape recordings were played into the combination.

The results were very similar to the results obtained previously from a computer arrangement improvised from commercial test equipment. A photograph of the breadboard circuit is given in Fig. 7.

The remaining time was devoted to improving various circuits in the breadboards. An improved integrator was developed for the oscillator tuning circuit, an investigation was made of true-RMS detectors which could be used, and a precise-gain amplifier was designed and tested.

B. DRIFT ANGLE ATTACHMENT

1. Report of Progress

It was reported in Ref. 1 that a drift angle attachment, together with associated test equipment, had been built and was in the process of being tested. Since that time, several factors have made it necessary and desirable to redesign and rebuild these units. These factors are outlined below, and the major work which has been accomplished in each category is described.

a. Improved Design

During the process of testing, certain improvements over the original design were conceived. New circuits which were designed and incorporated in the system include a wide-band remote gain control circuit, and a transformerless full-wave rectifier with both input and output referenced to ground.

Another improvement is a circuit which will remove the control voltage from the servo motor when the drift angle potentiometer hits a limit switch, but will permit recovery when the error signal reverses polarity.

b. Signal Recording Capability

The original attachment had been visualized as a simple drift angle measuring device, and had been designed with compactness and simplicity as primary goals. However, as work progressed on the ground speed attachment, it was realized that the drift angle flight tests could be utilized for obtaining tape recordings which would be very valuable in the development of the ground speed computer. As a result, a magnetic tape recorder was added to the aircraft instrumentation, and the following changes were made to the drift angle attachment.

The test set, which was originally intended for bench and flight-line use, was expanded in function and converted into a control box which will be accessible to the observer during flight.

The Doppler amplifier plug-in in the drift angle computer was redesigned to permit a wide band of frequencies to be amplified and transmitted to the tape recorder. A band-pass filter is switched into the circuit for drift angle operation.

Switching circuits were devised which would permit the position of the radar antenna to be controlled from the drift angle control box, and permit the scan to be turned off and on.

c. Radar Considerations

In preparing to integrate the attachment into the radar circuits, it became necessary to make some changes in both the radar and the attachment in order to make them compatible.

Changes in the drift angle attachment itself because of the compatibility problem were minor ones, involving the wiring of switches in the control box. Some of these were due to the added complexity required for recording purposes, others were to relieve the crowded condition of the radar control box.

The big problem involved a basic change in the radar itself. This change would not have been necessary if the drift angle computer had its own IF post amplifier as the attachment to the AN/APG-46 radar had. However, it was felt that a saving in size and complexity could be realized if the sum output of the radar IF amplifier could be utilized for the drift angle input. The difficulty with this arrangment arises from the fact that the drift angle computer requires an ungated post amplifier, but also requires a range gate which is normally generated in the radar by gating the post amplifier. This problem was handled by developing a video gate circuit which could be inserted in the video section of the radar ranging circuits, eliminating the need for a gated post amplifier.

At present the redesigned drift angle attachment and associated bench test equipment have been built, and are undergoing final tests. Photographs of the drift angle components are shown in Figs. 1 through 6. The work of modifying the radar plug-in units to incorporate the video gate circuit is under way.

2. Drift Angle Modes of Operation

The redesigned drift angle attachment will be in operation whenever the radar is switched to the drift angle mode. The attachment, however, has three sub-modes -- drift angle, record and test. The drift angle mode permits the computation of drift angle in the normal manner, and the result is indicated on the meter on the drift angle control box.

The record mode stops the antenna scan, permits the antenna azimuth angle to be selected by switches on the control box, and switches out the band-pass filter to permit the recording of a wide band of frequencies. In addition to the Doppler spectrum which is recorded on magnetic tape, a second channel will record a dc voltage which is positive when the right sample relay is closed, negative when the left sample relay is closed, and zero when neither is closed. These relays can close only when the antenna azimuth servo stops. Therefore the recordings indicate when the antenna is moving, when it is stopped and receiving useable data, and whether it is pointing to the right or left of the aircraft heading. Individual signal recordings can be made of any of the azimuth angles provided, or the antenna can be made to scan manually by selecting the desired angle and then actuating the right-left switch at will. By making a simple wiring change in the control box, wide-band recordings can be made while the automatic drift angle scan is in operation.

The test mode turns on a 150 cps oscillator which provides an indication that the Doppler amplifier is operating properly, and also checks the balance adjustment. By operating the servo right-left switch, the servo motor can be made to run in either direction and the resulting change in drift indication observed on the meter. These tests are intended to be an aid in trouble shooting, and also a confidence check that can be made in flight if desired.

III. WORK FOR NEXT QUARTER

A. GROUND SPEED ATTACHMENT

During the next quarter, it is hoped that the design and the breadboard testing of the ground speed attachment can be completed. Work will begin on the packaging of a prototype unit.

B. DRIFT ANGLE ATTACHMENT

During the next quarter, the drift angle attachment will be bench tested, integrated with Radar Set AN/APQ-89(XAN-1) System No. 2, and the combined radar - drift angle system thoroughly checked out. At the same time, a second set of drift angle components will be built and tested. Flight tests of the drift angle attachment are scheduled for early calendar 1962.

C. UNGATED BOXCAR DETECTOR

An idea has been conceived which would permit the generation of the boxcar signal without the necessity of range gating. This would involve the design of a new type of boxcar detector which would respond to the peak amplitude of the video signal, rather than to the amplitude corresponding to the position of the range gate. It is expected that this circuit would be applicable to both drift angle and ground speed attachments.

If successful, this circuit would have little effect on the size or complexity of the attachment itself, but it would provide a big reduction in the capabilities required of the parent radar.

1. Monopulse techniques would not be required.

2. Air-to-ground ranging would not be required.

3. An alternate solution would be provided for the problem of using the normal radar post amplifier for the drift angle or ground speed signal source. Since automatic ranging would not be required in the navigation mode, the post amplifier could remain ungated, and alternate gating methods such as the video gate circuit mentioned in Sec. II-B would not be required.

A theoretical investigation of the idea is planned for the coming quarter. If the results are promising, the circuit will be designed and built into a plug-in unit which is interchangeable with the boxcar plug-in in the drift angle attachment. Thus the circuit can be easily included in the drift angle flight test program.

APPENDIX A

DETAILED REPORT ON THE GROUND SPEED ATTACHMENT DESIGN

By C. Andrew Hughey
Electronic Engineer

A. BACKGROUND

The derivation of ground speed from the intermodulation Dopper spectrum can be accomplished in several ways. Many of these methods have been discussed in detail in Ref. 1. After carefully considering all of the possibilites, it was decided to use the RMS-comparison technique as it appeared to best lend itself to instrumentation.

B. INSTRUMENTATION

1. General

The proposed block diagram, Fig. 17 of Ref. 1, was revised to facilitate instrumentation. The new block diagram is shown in Fig. 8. As shown in the diagram, the ground speed attachment is composed of three major sections, a boxcar circuit with associated low-pass filter, a crossover frequency tracker, and a frequency processor. The purpose of the boxcar detector is to range gate the video signal, and to extract the pulse-to-pulse modulation which is present whenever the aircraft is in motion. The output of the circuit is a complex waveform with a frequency spectrum which has been described in previous reports, (Refs. 1 and 2). The function of the circuits which follow is to identify a particular spectrum shape with respect to the antenna angle and aircraft velocity which produced it. The identification is accomplished by finding the crossover frequency.

The purpose of the crossover frequency tracker is to extract the crossover frequency from the intermodulation Doppler spectrum, while the purpose of the frequency processor is to store the right and left crossover frequencies, and to obtain their sum and difference. The sum is a function of ground speed, while the difference is a function of the error in indicated drift angle.

2. Crossover Frequency Tracker

The crossover frequency tracker is composed of six basic units as shown by the block diagram of Fig. 9. The first of these units is a balanced mixer composed of a type 7360 beam deflection tube and associated circuitry. The mixer has two inputs: a variable frequency

carrier operating in the vicinity of 48 kc, and the intermodulation Doppler signal which contains frequencies from 1 to 1,500 cps. One of the main reasons the type 7360 mixer was chosen was that no input transformer was needed, thus allowing audio inputs as low as one cycle per second without huge components. The output of the mixer is a reproduction of the intermodulation Doppler spectrum translated in frequency from zero to roughly 48 kc. A broad-band tuned circuit in the mixer eliminates the low-frequency output which would otherwise be present. The carrier is suppressed 50 to 60 db.

The next unit in line is the filter assembly. The purpose of this unit is to supply two detectors with signals whose RMS values are equal, using the output of the balanced mixer. This is accomplished by amplifying the balanced mixer output in a three-stage, transistorized amplifier with a class B, push-push output. The signal is then split into two legs; one leg going into a resistive voltage divider, the other leg going into a very narrow band-pass filter. The filter output, basically a single frequency signal of 48 kc, is then again amplified in a very stable, constant gain, transistorized amplifier with a voltage gain of about forty.

The selected filter is of the vibrating ferrite rod type. It was chosen because of its stability, isolation, and extremely high Q. It has a pass band of 10 cps at a frequency center of 48 kc and a slope of 12 db per bandwidth octave. Because of the low input impedance of this device, 15 ohms, and the fact that it rejects 99% of the applied signal, a relatively high amount of power is required to drive it. For this reason, the class B amplifier preceding it is capable of an output of about one watt. Transistors were chosen for this amplifier because the filter it was to drive was basically a current device. A vacuum tube amplifier utilizing a cathode follower output was attempted but was abandoned when it appeared transistors would do a better job and make a smaller package. The output amplifier was also transistorized when it was discovered that a circuit utilizing a large amount of feedback could hold its gain constant within ± 0.5% over the temperature range. Transistors were desired here because of their lack of sensitivity to power supply voltage and time.

The output of the two legs of the filter unit passes on to a circuit which is composed of two detectors and a dc comparator. The purpose of this circuit is to convert the inputs to dc signals of opposite polarities, add them in the comparator, and present a dc error voltage output whose magnitude and polarity indicates the relative size of the applied signals. Since one input is shaped noise, the detectors must produce an output which is proportional to the true RMS of the applied waveform. It has not been determined at this time if a linear detector will approximate the true RMS closely enough to be of use. However, a true RMS type of detector utilizing germanium diodes has been developed to replace the linear detector in use at present. Comparative tests will be conducted to determine whether or not the added complexity of the

true-RMS detector is justified by an increase in accuracy. The comparator circuit is a resistive adding network with equal resistance in each arm.

The output of the comparator is fed to an integrator circuit. This circuit performs no precise mathematical computation, but merely acts as a large capacitor and high-gain amplifier in averaging and amplifying the error signal from the comparator.

The first circuit attempted for this unit was a straightforward dc amplifier type of integrator. This circuit was abandoned when it was found that the output varied greatly with time and with small changes in power supply voltage. The next attempt was a high-gain ac amplifier with both input and output chopped to convert from dc to ac and back to dc. The output was then strapped back to the input by means of a large capacitor to provide the integrating action. This circuit, using type 2N1026 transistors as electronic choppers, worked very well. It had no drift and very little change in gain with respect to time and variations in B+. The circuit currently being used has a voltage gain of about 26 db and a time constant of about 20 seconds.

The integrator output feeds a voltage-tunable oscillator whose output frequency is proportional to its input voltage. The oscillator is of the Hartley type with a voltage sensitive diode across its tuned circuit. The capacitance of this diode, when back biased, changes as applied voltage changes. Therefore, a change in input voltage changes the resonant frequency of the tank, and thus changes the output frequency of the oscillator.

The oscillator output becomes the carrier input of the balanced mixer previously mentioned. Also, it is fed to another mixer. This mixer has, as its second input, the output of the filter or narrow-band leg of the previously mentioned filter unit. The difference of these two frequencies is the same as the frequency in the intermodulation Doppler spectrum being tracked by the filter loop, or, with proper calibration, the crossover frequency. This holds true regardless of the drift in the oscillator or in the center frequency of the narrow band filter. In operation, the oscillator output is fed directly to the control grid of a pentode operating in its non-linear region. The filter output is amplified, clipped, re-amplified, and fed to the suppressor grid. The output of the mixer is then passed through a low-pass RLC filter so that only the crossover frequency remains.

The foregoing explanation may be clarified somewhat by a brief recapitulation. When the intermodulation Doppler spectrum is applied to the input, it is transformed in frequency to a point determined by the oscillator frequency, F_o, and is split into two legs. One leg contains the scale factor voltage divider which reduces the amplitude of the wide-band signal by a predetermined ratio. The other leg contains

a filter which produces an indication of the voltage level at a specific frequency, F_F. If the narrow band filter output is less than the wide band output, the oscillator is driven to a higher frequency, increasing the amplitude of the filter output, until a carrier frequency is reached where the narrow band output equals the wide band output. If the narrow band output is higher than the wide band output, the oscillator is lowered in frequency until a zero is reached. When the loop stabilizes, the output of the second mixer is the crossover frequency.

3. Frequency Processor

The output of the crossover frequency tracker may be expected to vary in a random manner, due to the noise-like nature of the input signal. Some method of averaging must be employed to obtain useful results. Also, different crossover frequencies may be obtained from the left and right samples, due to uncompensated drift angle. This must be corrected. Finally, the frequency must be made available in a form which can be read on a meter or used by other equipment. These functions are performed by the frequency processor, shown in block diagram form in Fig. 10.

The first unit in the frequency processor is a frequency to dc voltage converter. This is done by amplifying and clipping the sine wave output of the crossover frequency tracker to form a square wave. This square wave is then amplified and applied to a counter circuit that differentiates the square wave and passes the positive spike into a capacitor bypassed by a large resistance. By this method, the voltage across the capacitor is proportional to the applied frequency.

If the resistor bypassing the capacitor in the counter were actually tied between the capacitor and a variable negative voltage, it would be possible to select a negative voltage such that, for a constant input frequency, the capacitor voltage would be zero. This is the method to be used in the frequency to voltage converter. The voltage on the capacitor is fed through a chopper and servo amplifier to a servo motor which drives a potentiometer changing the negative voltage on one end of the bypass resistor until the capacitor voltage is zero. Now, the negative voltage at the wiper arm of the potentiometer is proportional to input frequency. This also solves the problem of storage as the servo motor may be turned off and the potentiometer locked in place between samples.

By utilizing two potentiometers and a clutch-brake arrangement, this method can serve for both right and left samples. When sampling on the left for instance, the motor can drive the left potentiometer as described above while the right potentiometer is disengaged from the circuit and braked in position. Then, when sampling on the right, the right potentiometer can become active while the left is braked. By this method, an average crossover frequency reading for both channels is available at any time.

Now, by ganging potentiometers and by using two comparator circuits, it is a simple matter to obtain a voltage proportional to the average of the left and right channels and a voltage proportional to the difference between the right and left channels. The average of the two channels is proportional to the average of the crossover frequencies sampled on the right and left and may be read out as a frequency calibrated in cps. The difference between the two channels indicates a drift angle error and may be used to recenter the antenna scan.

Initial flight tests of the ground speed attachment will be used to record the average crossover frequency as indicated by the sum output of the frequency processor. If this output exhibits a linear relation with respect to speed, the meter can be calibrated directly in knots. If not, a special meter scale or frequency to speed converter unit will be required to read speed directly.

C. FABRICATION AND TESTING

The crossover frequency computer and part of the frequency processor have been breadboarded and tested. The frequency processor is complete only through the storage capacitor of the counter unit. It is hoped that the servo device necessary to complete the counter unit will soon be available. The breadboard in its present state may be seen in Fig. 7.

As soon as the breadboard appeared capable of tracking crossover frequency, tests were conducted to find its accuracy in measuring the crossover frequencies of the raw spectrum recordings made during the original drift angle flight test program. The results of this test appear in Table 1.

TABLE 1 - CROSSOVER FREQUENCY VS. SPEED AND ANTENNA ANGLE

Ground Speed (Knots)	Angle off Ground Track (Degrees)					
	0	3	6	10	15	20
200	112	115	124	139	165	188
300	109	111	123	143	177	199
400	116	123	156	206	257	294

Results of breadboard computer tests on recordings of Drift Angle Flight 127, runs 1, 2 and 3

Note: Each reading is the average of five readings on the left and five readings on the right. Frequencies are in cps.

Also, a plot of crossover frequency versus speed is shown in the graph of Fig. 11. This may be compared with a similar graph of results obtained from the same data by the methods described in Appendix C of Ref. 1. This second graph is shown in Fig. 12. Since the breadboard computer was only approximately calibrated for this test, a bias error exists in the results causing a shift of axes between the two graphs. Also, the low-pass filter which previously attenuated the frequencies below 15 cps was not used this time, causing the low crossover frequencies to read lower than before. All in all, the results seem to show good correlation between the two methods. Notice that the inclusion of the lower frequencies produced a more linear frequency vs. speed response with a resultant increase in sensitivity at the low speeds. This effect was predicted in Ref. 1.

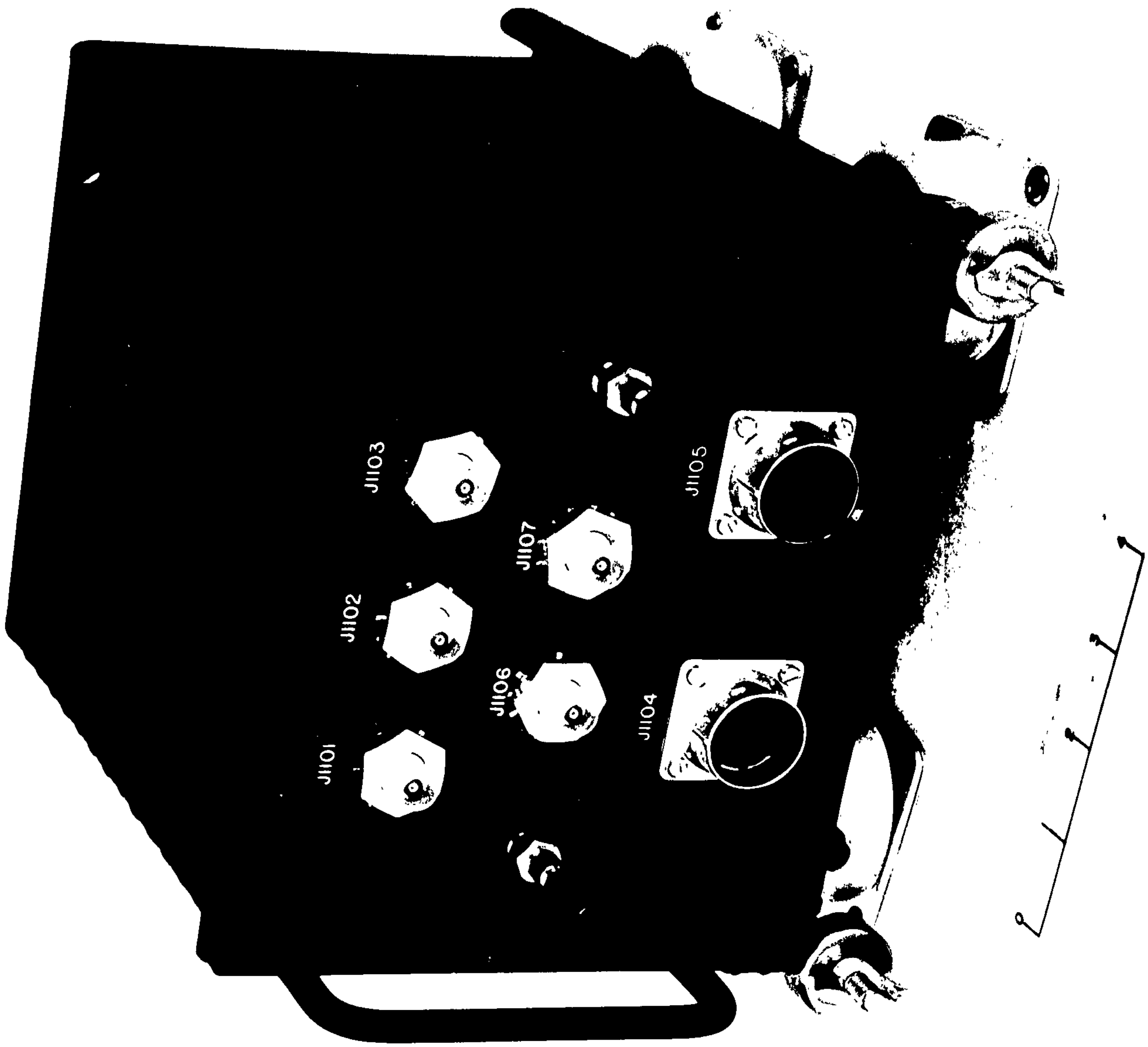

FIG. 1 - DRIFT ANGLE COMPUTER

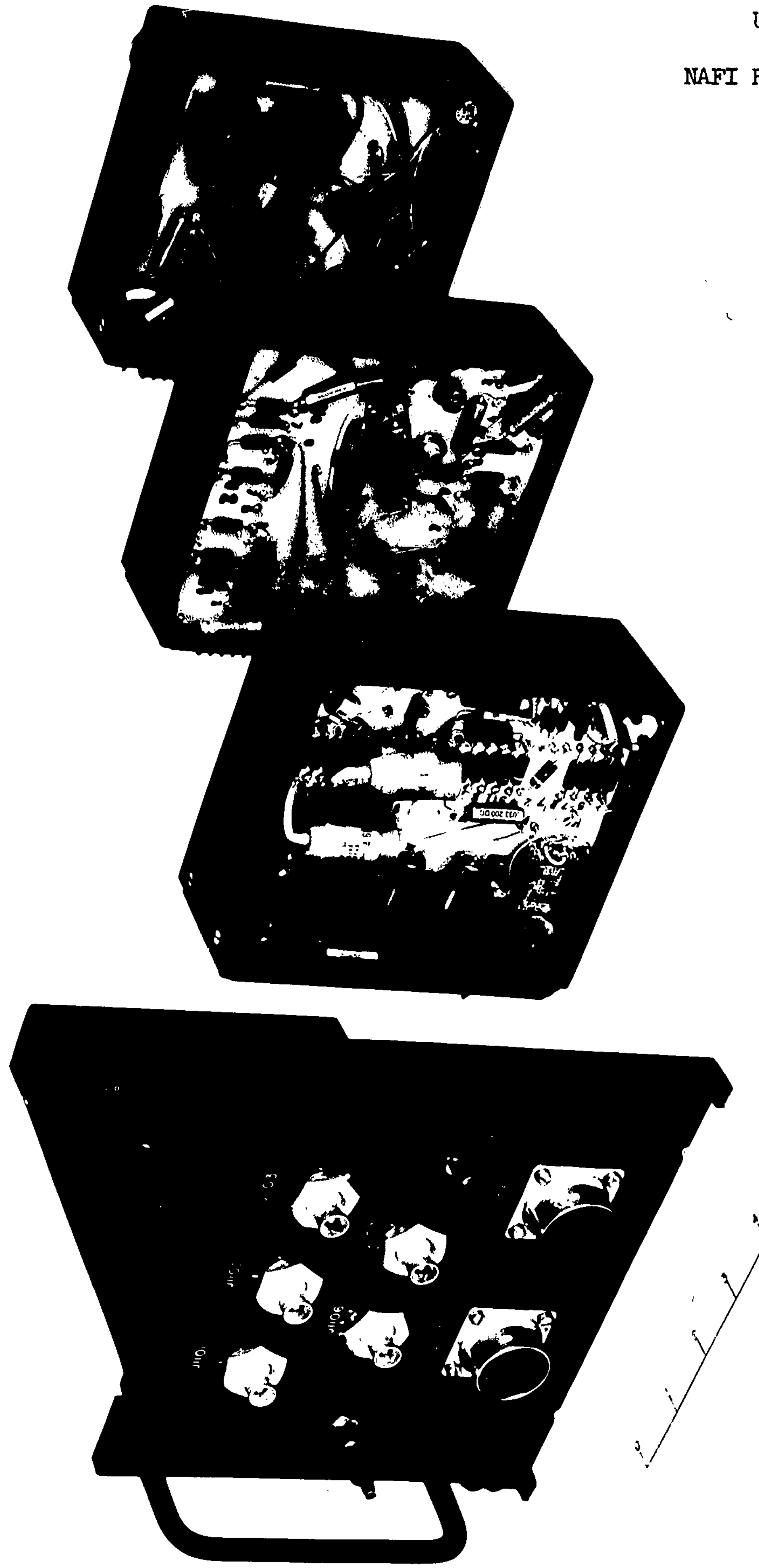

FIG. 2 - DRIFT ANGLE COMPUTER -- EXPLODED VIEW

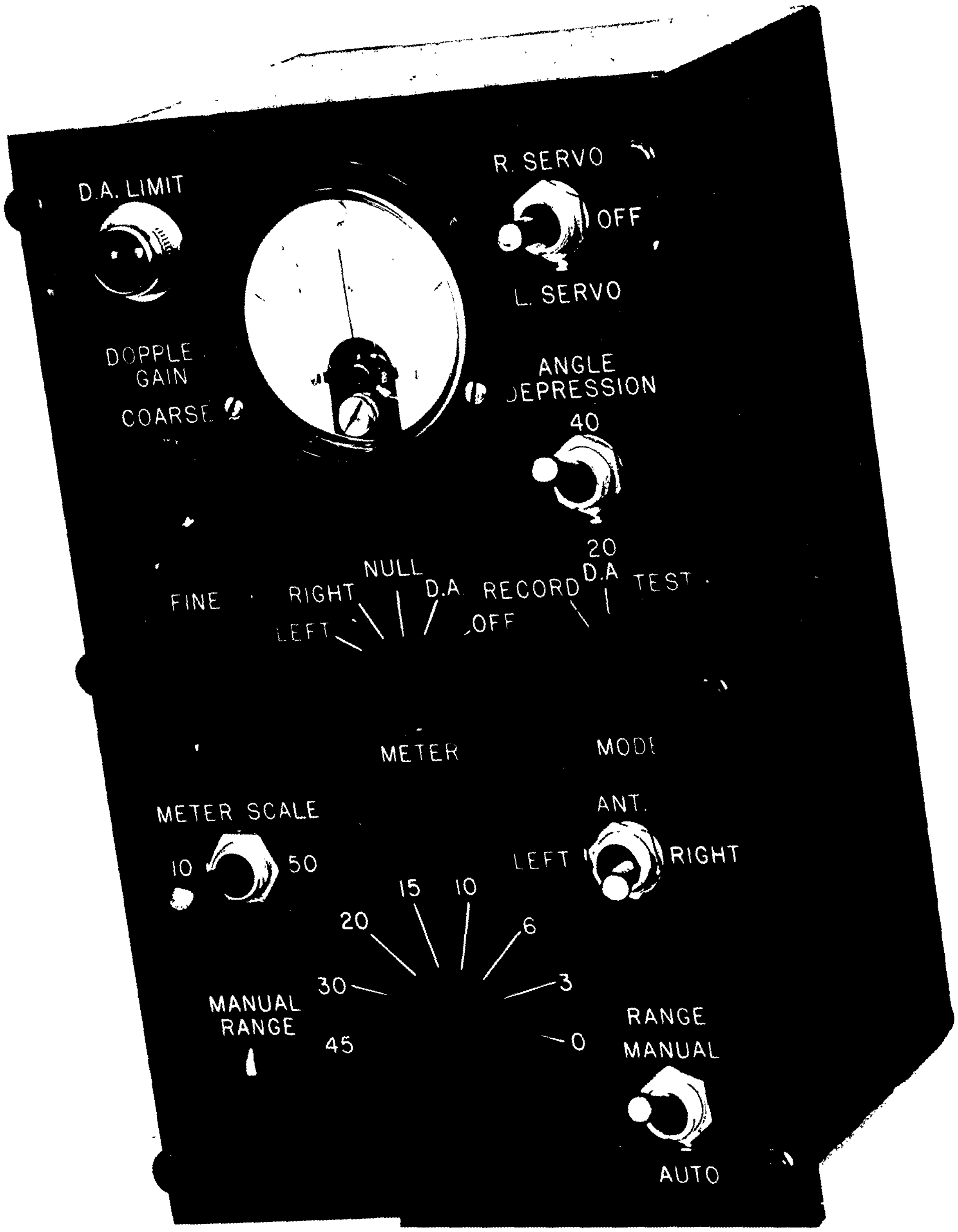

FIG. 3 - DRIFT ANGLE CONTROL BOX

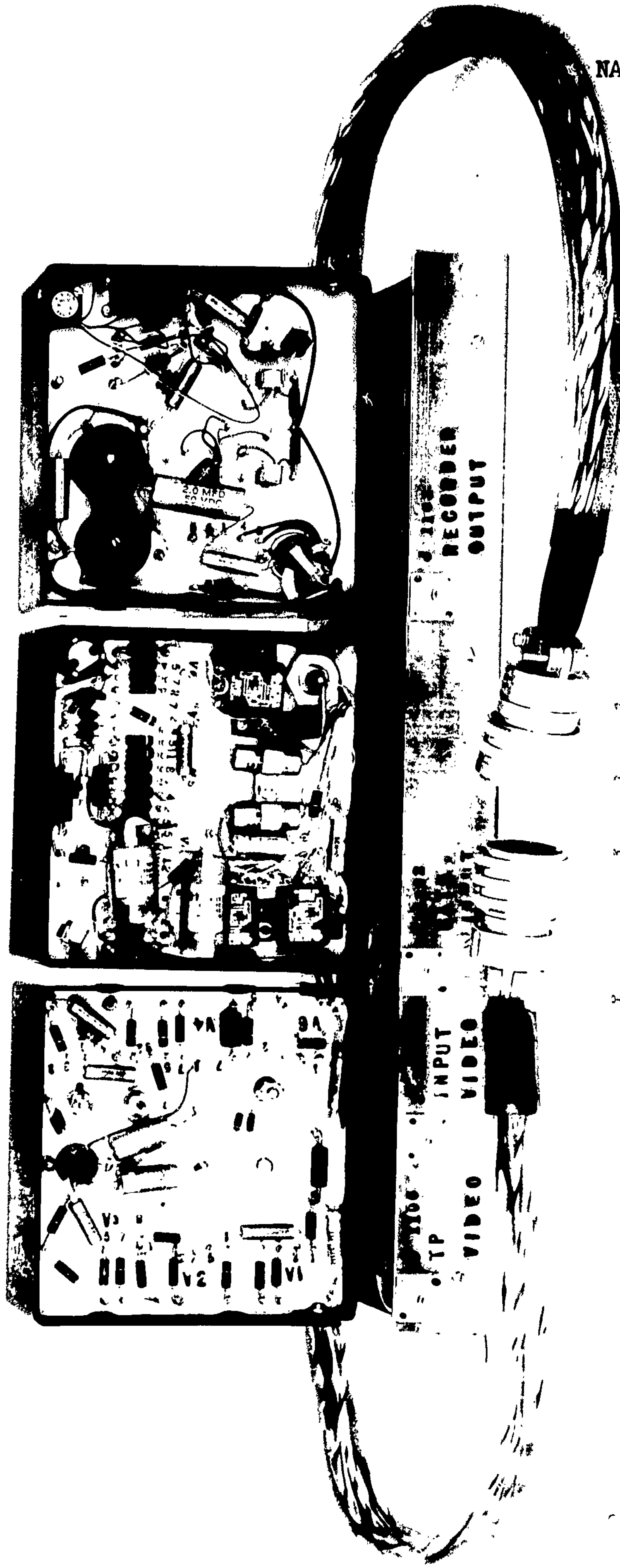

FIG. 4 - DRIFT ANGLE COMPUTER BREADBOARD CHASSIS WITH PLUG-INS -- FRONT VIEW

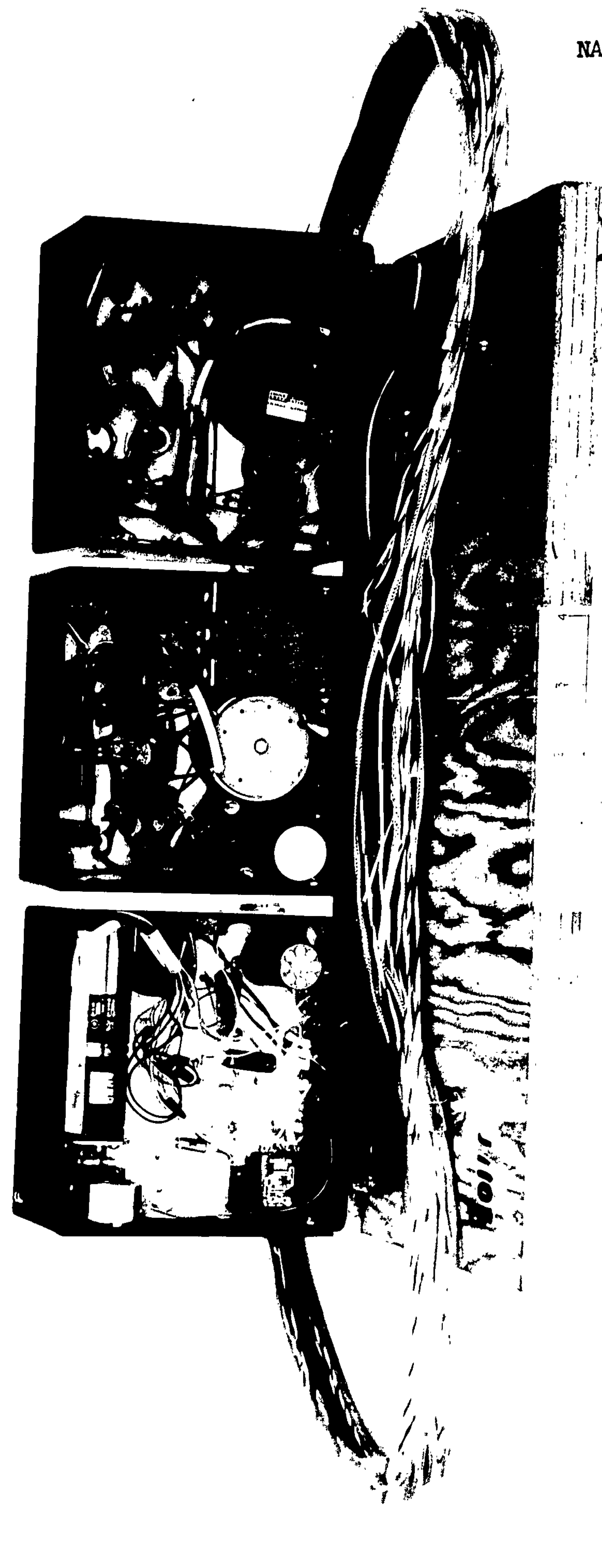

FIG. 5 - DRIFT ANGLE COMPUTER BREADBOARD CHASSIS WITH PLUG-INS -- REAR VIEW

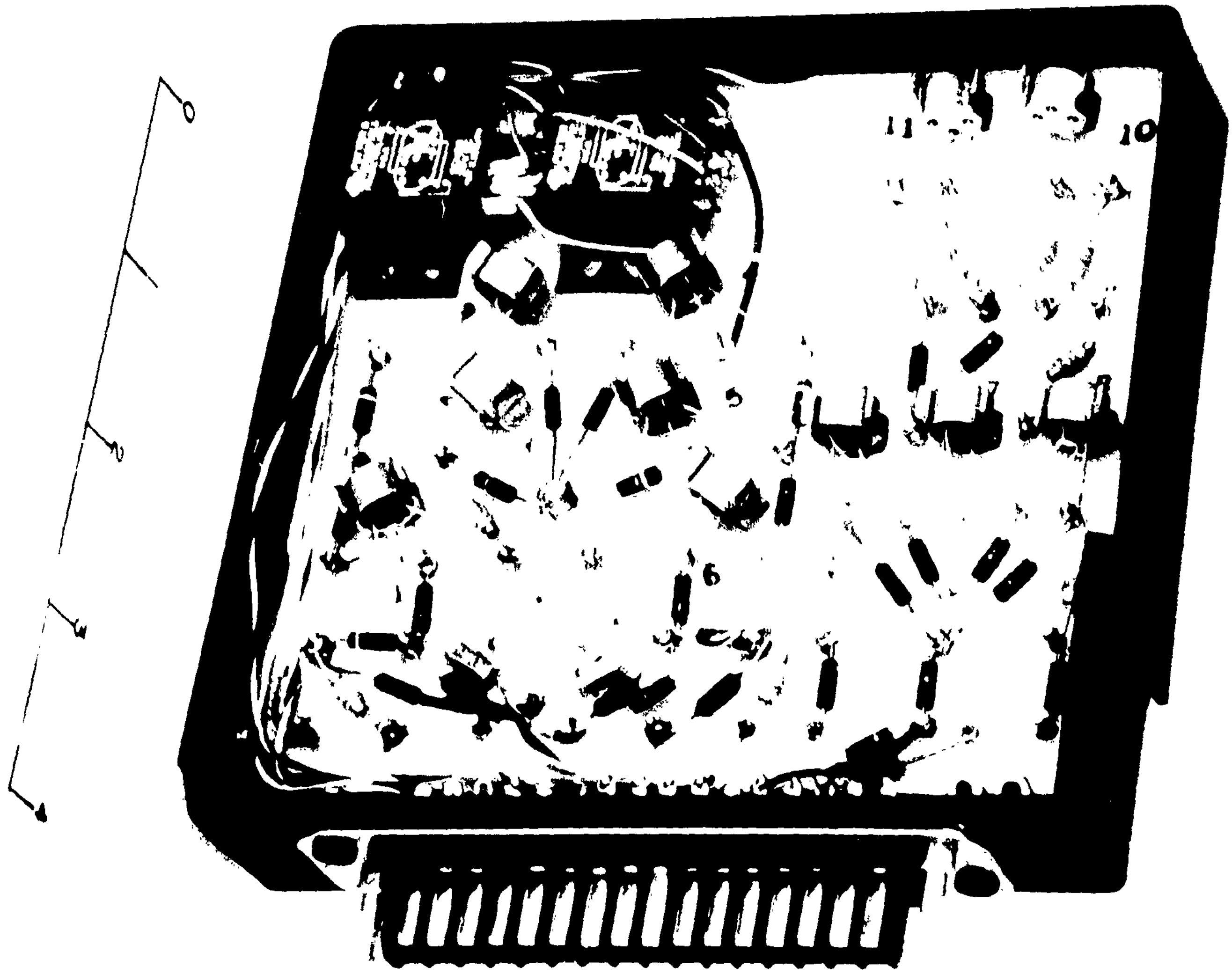

FIG. 6 - DRIFT ANGLE VERSION OF RADAR POSITION TRANSFER PULSE GENERATOR

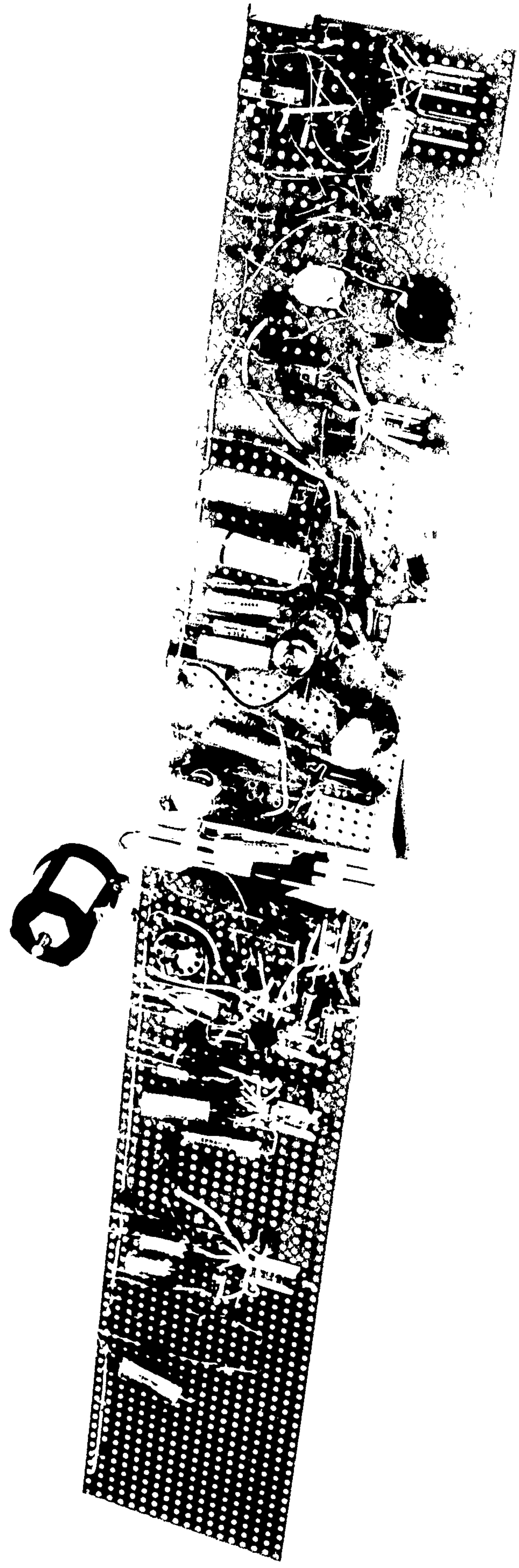

FIG. 7 - BREADBOARD OF GROUND SPEED COMPUTER

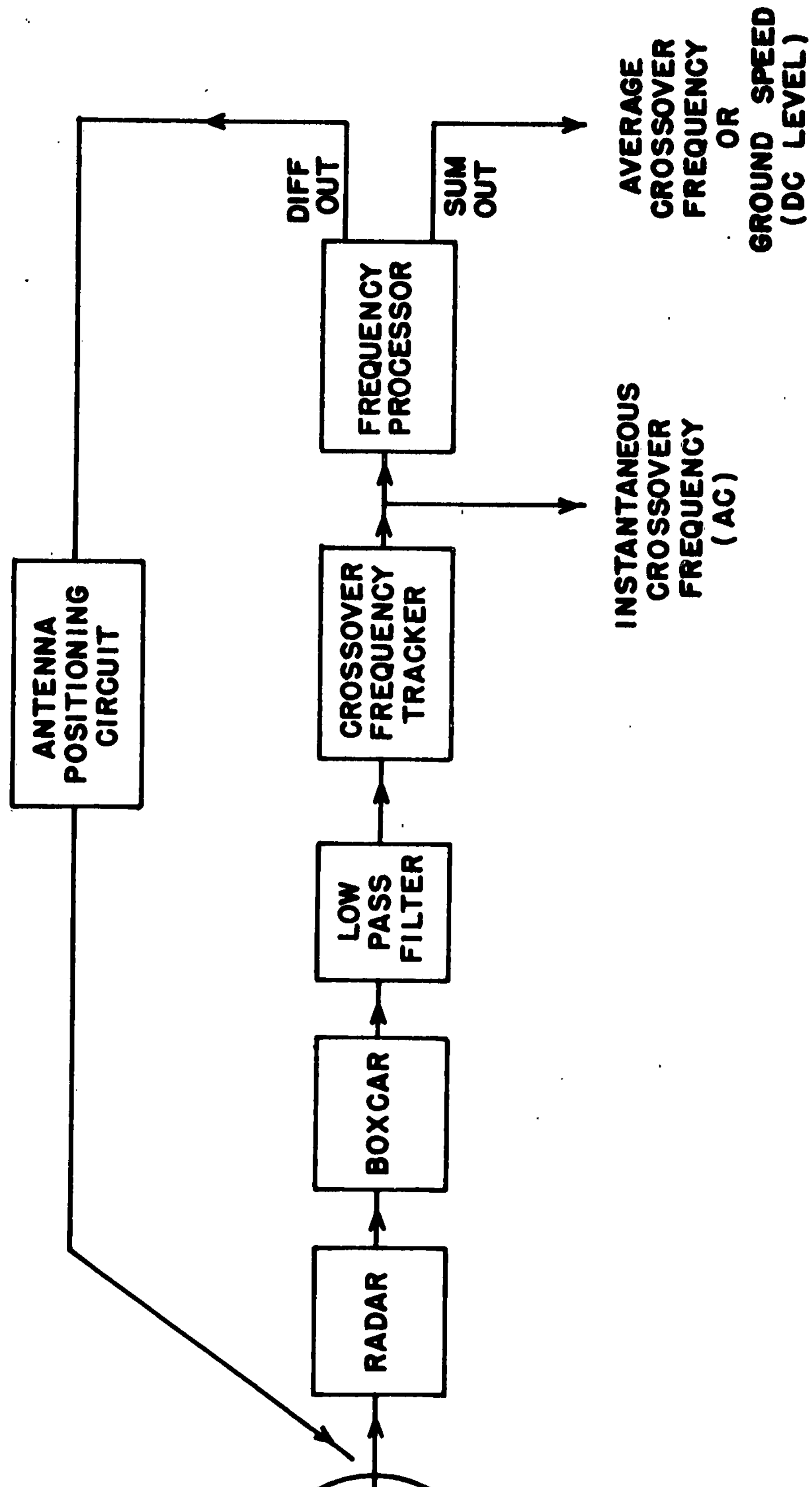

FIG. 8 - BLOCK DIAGRAM OF GROUND SPEED, DRIFT ANGLE SYSTEM

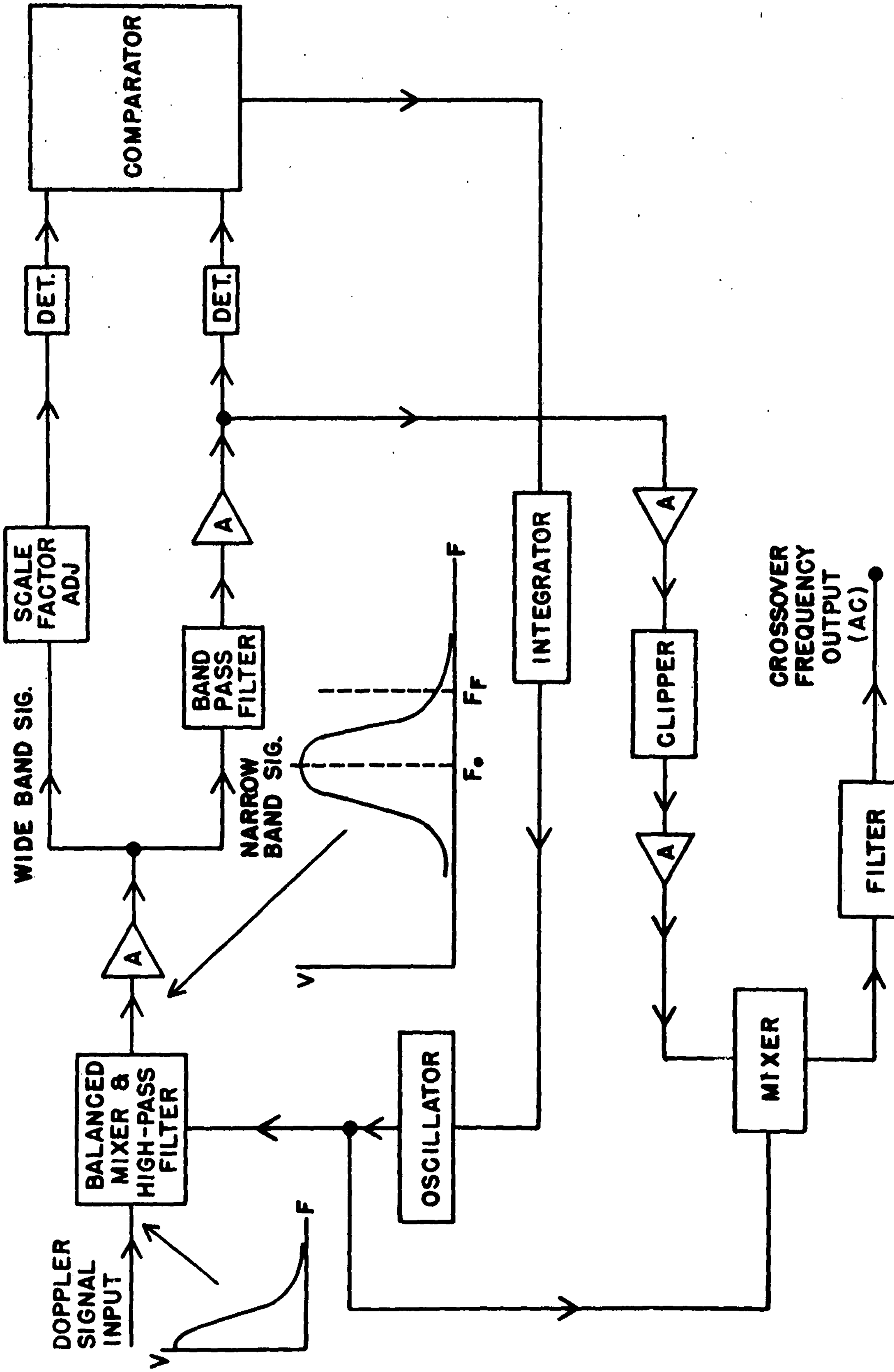

FIG. 9 - BLOCK DIAGRAM OF CROSSOVER FREQUENCY TRACKER

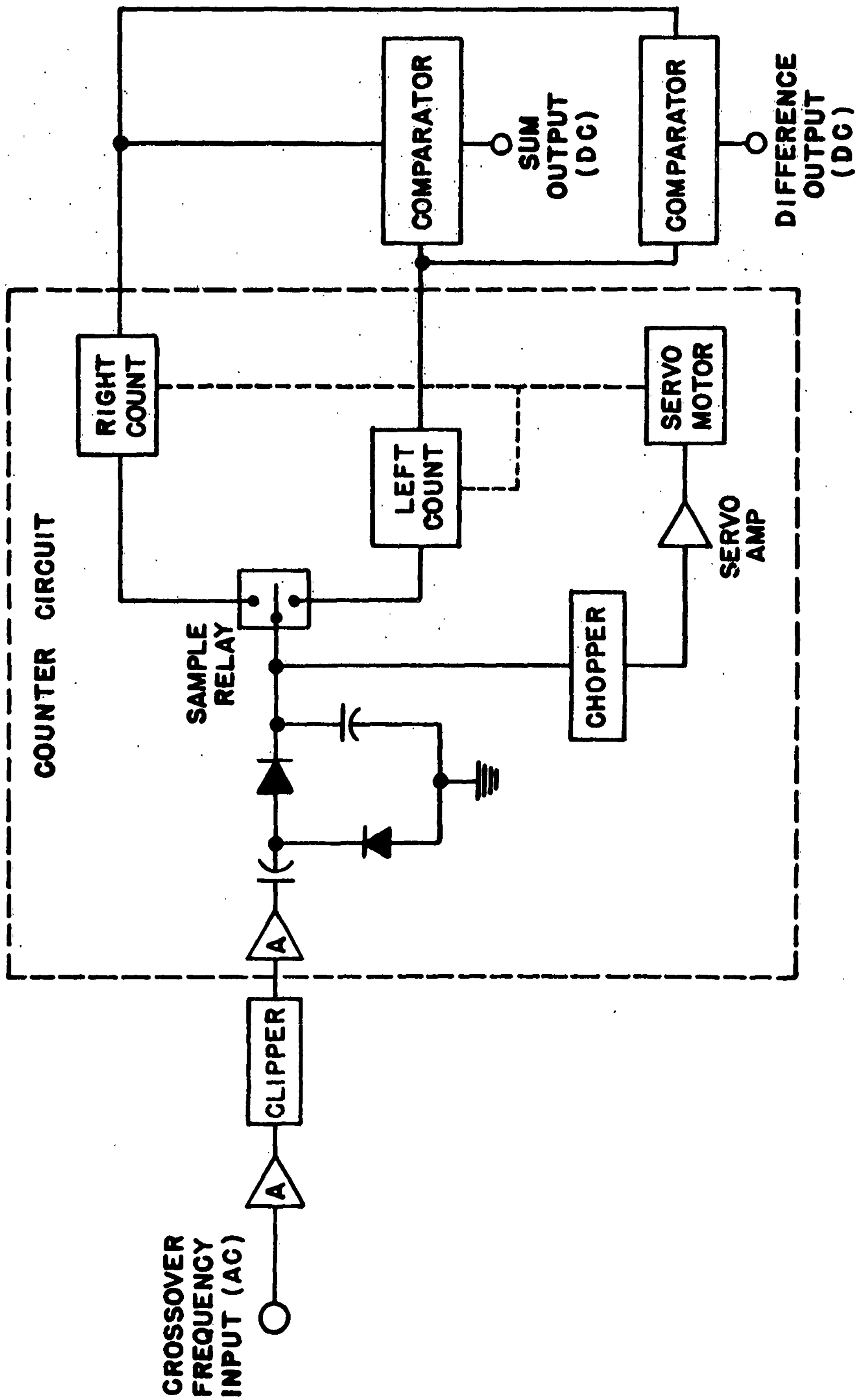

FIG. 10 - BLOCK DIAGRAM OF FREQUENCY PROCESSOR

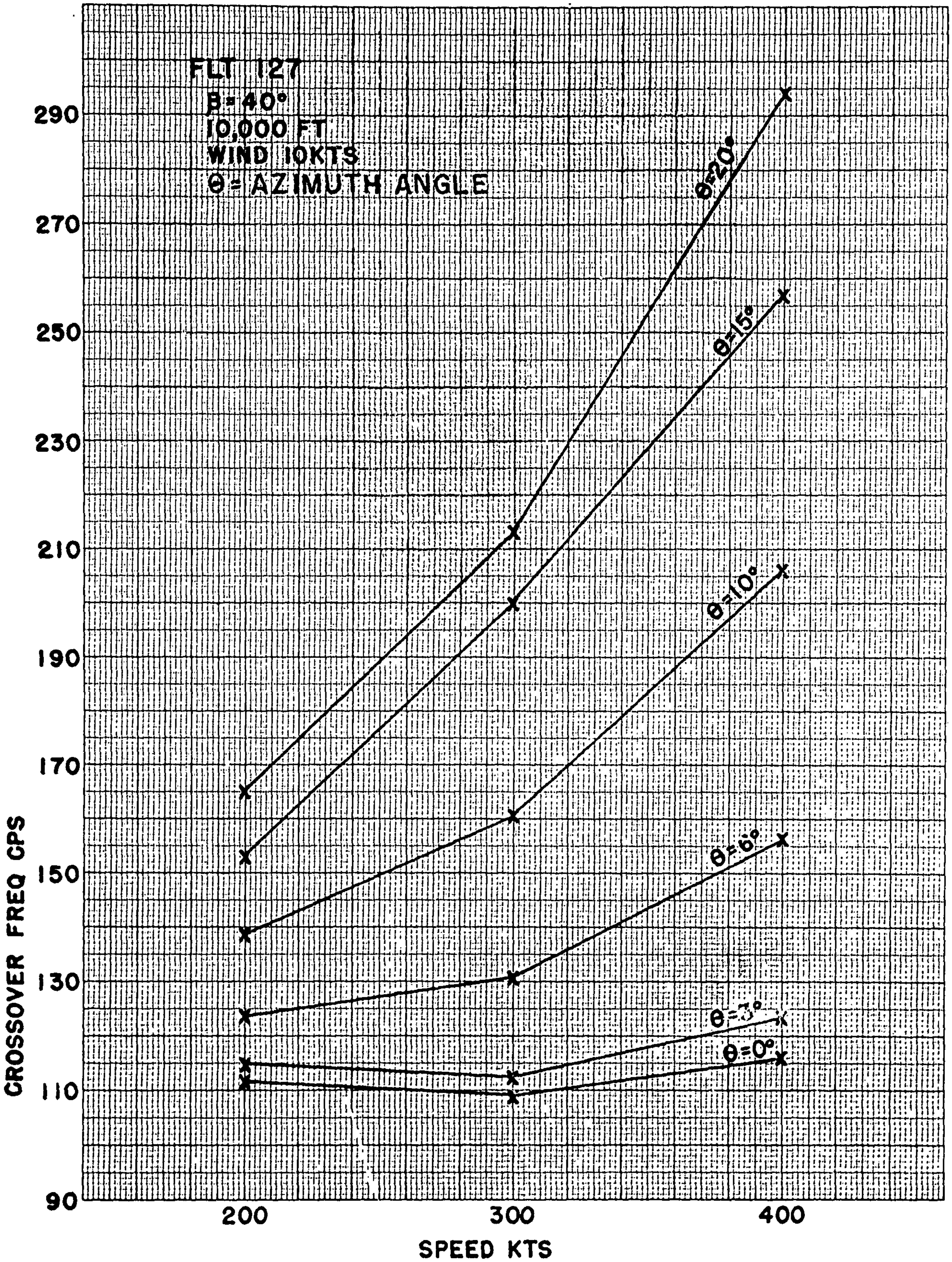

FIG. 11 - CROSSOVER FREQUENCY VS. SPEED AS MEASURED WITH GROUND SPEED COMPUTER BREADBOARD

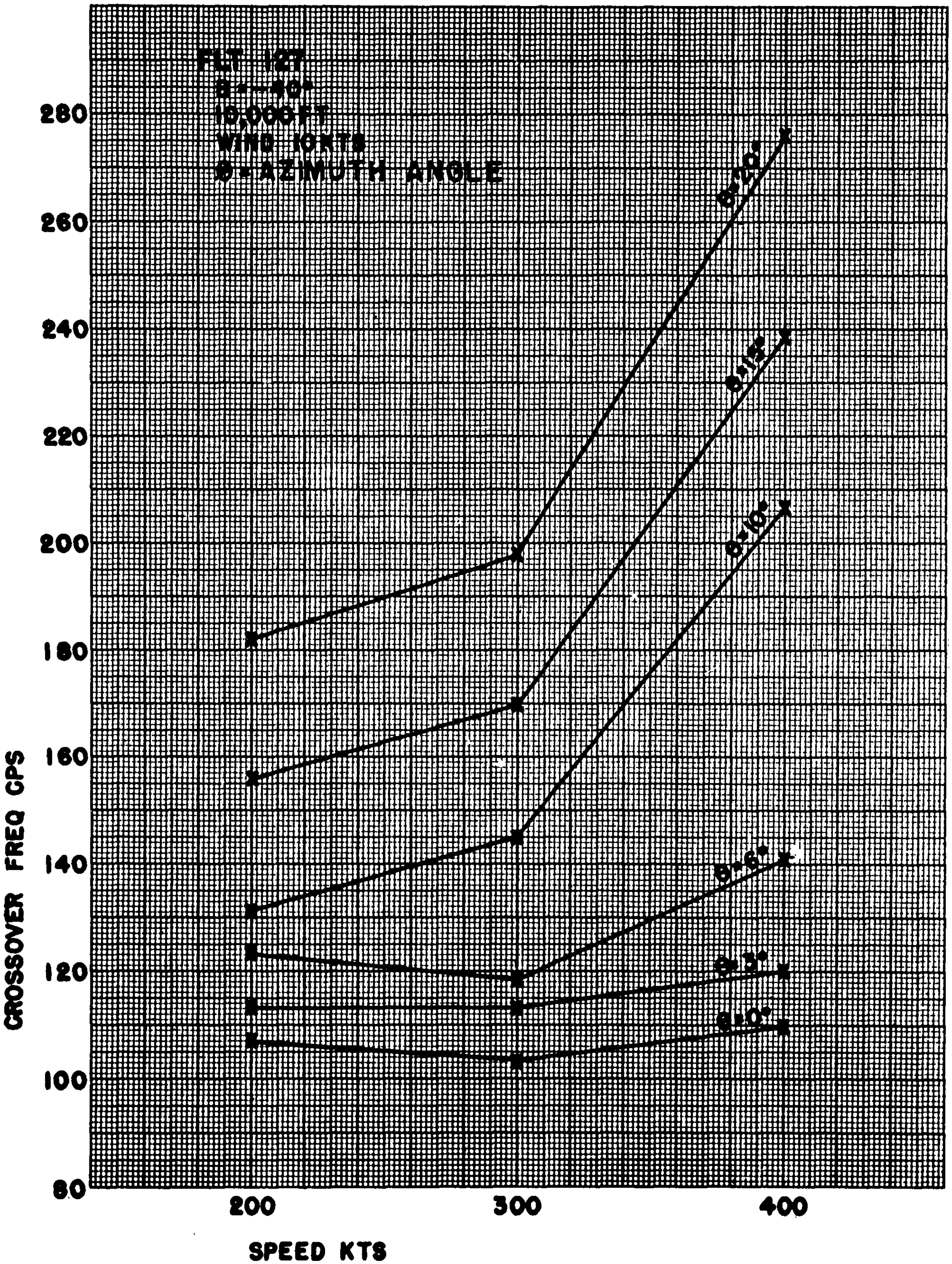

FIG. 12 - CROSSOVER FREQUENCY VS. SPEED AS MEASURED WITH TEST EQUIPMENT

REFERENCES

1. U. S. Naval Avionics Facility - Confidential TR-56

2. U. S. Naval Avionics Facility - Confidential TP-67 (Part 1 and Part 2)

3. U. S. Naval Avionics Facility - Confidential TR-5

4. U. S. Naval Avionics Facility - Confidential TR-22

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